Experimental Problem: Low-pass and high-pass filter circuits

Introduction

Low-pass and high-pass circuits, developed in electronics and signal processing, modify and control a signal's response as a function of frequency.

A low-pass circuit passes low-frequency signals while attenuating or blocking high frequencies. It is useful for smoothing signals or removing unwanted high-frequency components such as noise and interference.

A high-pass circuit passes high-frequency signals while attenuating or blocking low frequencies. It is useful for emphasising sharp signal components, such as harmonics or high-frequency detail.

Resistors, capacitors and inductors interact to produce the high-pass or low-pass behaviour.

These circuits can be described by Bode plots, which show a system's frequency response: how signals are attenuated or transmitted according to frequency.

Bode plots show the response at different frequencies and help design suitable signal filtering and processing, as in Figure 1.

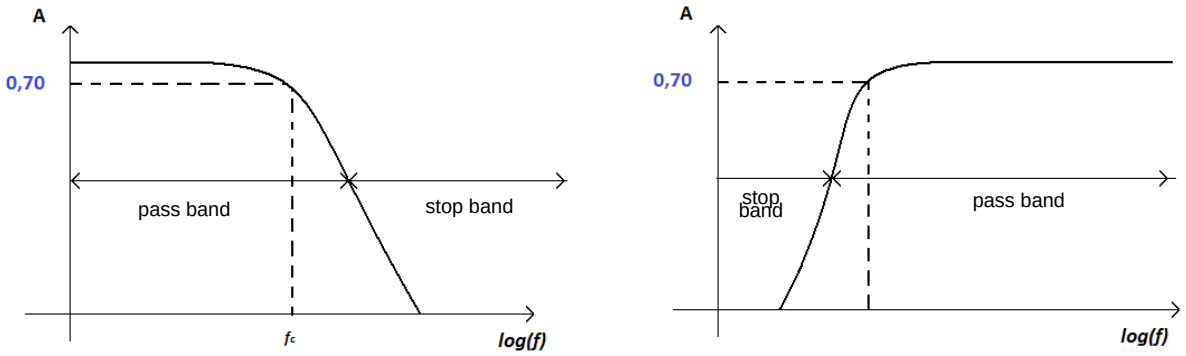


Figure 1. Bode plots for low-pass and high-pass circuits.

Take the cutoff frequency to occur at $V_{salida} = 0{,}7V_{entrada}$.

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Understanding the frequency response of high-pass and low-pass circuits lets us design efficient signal filters and processors.

Applications of low-pass circuits include:

- ✓ Loudspeaker audio processing.
- ✓ Anti-aliasing filters.
- ✓ Communications interference-rejection filters.

Applications of high-pass circuits include:

- ✓ Audio equalisation.
- ✓ Crossover filters.
- ✓ Signal-analysis measuring instruments.

These designs are useful in electronics, medicine, telecommunications and instrumentation.

Though hidden from view, these circuits are vital to these fields and technologies. Their control of energy flow and signal transmission opens new possibilities in communications and electronics. These discrete components play an essential role in modern progress, as illustrated in Figure 2.



Figure 2. Low-pass electronic circuit designs in real devices.

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Theory note

low-pass filter

Figure 3 shows an RC circuit called a

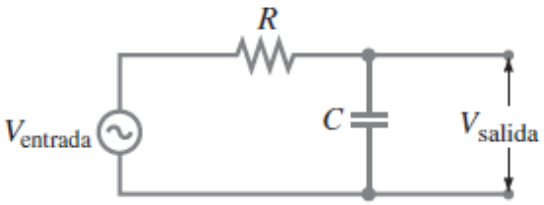


Figure 3. RC low-pass filter circuit.

It is a low-pass filter because it transmits low-frequency signals with less attenuation than high-frequency AC signals.

The filter gain, or voltage ratio, is

$$A = \frac{V_{salida}}{V_{entrada}} = \frac{1}{(4\pi^2 f^2 R^2 C^2 + 1)^{\frac{1}{2}}}$$ Equation 1

high-pass filter

Figure 4 shows an RC circuit called a

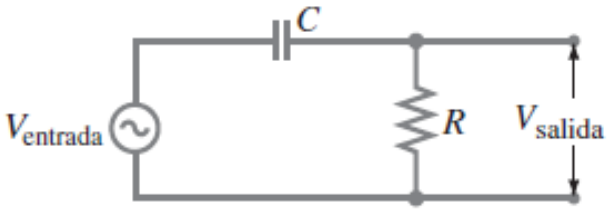


Figure 4. RC high-pass filter circuit.

It is a low-pass filter because it transmits low-frequency signals with less attenuation than high-frequency AC signals.

The filter gain, or voltage ratio, is

$$A = \frac{V_{salida}}{V_{entrada}} = \frac{2\pi f RC}{(4\pi^2 f^2 R^2 C^2 + 1)^{\frac{1}{2}}}$$ Equation 2

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Equipment

- ✓ Function generator
- ✓ Oscilloscope
- ✓ 1 kΩ resistor
- ✓ 1 µF capacitor
- ✓ Multimeter
- ✓ Connecting leads

Procedure (20 points)

Part A: Low-pass circuit

- *Experimental setup*

1. Open the VISIR HIVE Laboratory from the Aprende U platform. The workspace resembles Figure 5 and lets you build circuits.

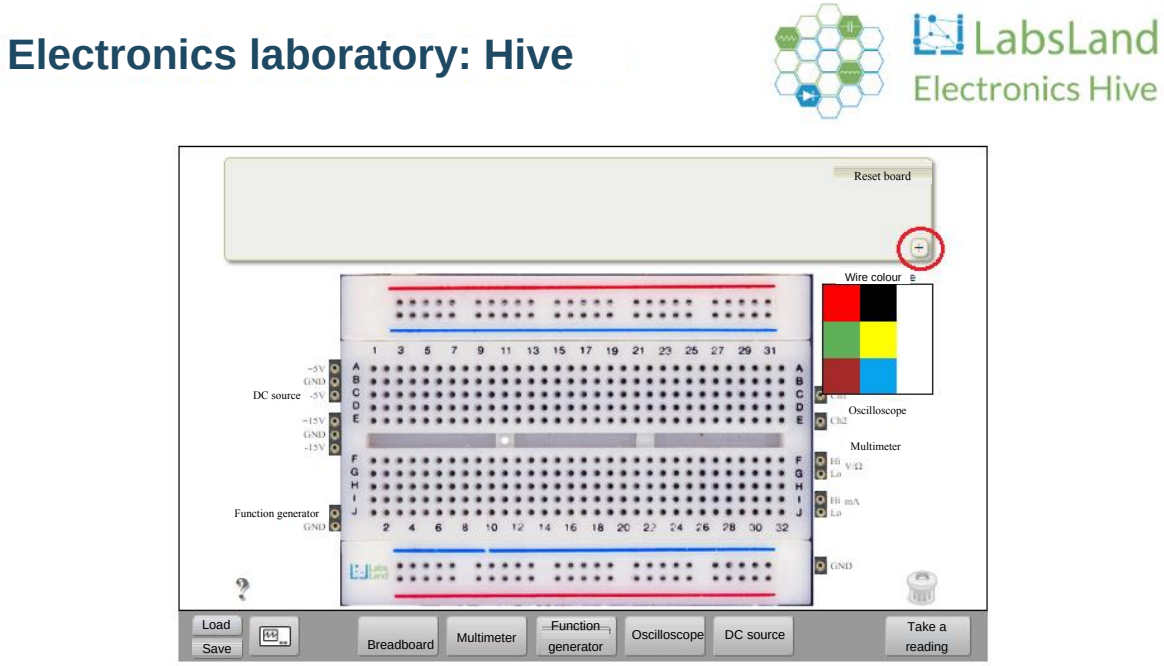


Figure 5. HIVE Remote Laboratory for circuits.

2. In the VISIR remote laboratory, select "Advanced experimentation" and click Access.

3. Add a $\mathbf{1\mu F}$ capacitor and a $\mathbf{1k\Omega}$ resistor to the board.

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4. On the breadboard, build the circuit in Figure 3 using the selected resistor and capacitor.

5. Connect the signal generator:

- Connect “Function generator” to the resistor's first terminal (left on screen).

- Connect the resistor's other terminal (right) to the capacitor's first terminal (left).

- Connect the capacitor's other terminal (right) to ground, “GND”.

6. Connect oscilloscope channels to measure the generator and capacitor voltages:

- Connect oscilloscope “Ch1” to the resistor's first terminal (left, already connected to the function generator).

- Connect “Ch2” to the capacitor's first terminal (left, connected to the resistor).

• *Measurement* ***(3 points)***

7. Separately, connect the resistor terminals to the multimeter. Select resistance mode (Ω), click Take measurement, and record the actual resistance and uncertainty in Table 2.

8. Repeat for the capacitor, setting the multimeter to capacitance mode (F). Record the actual capacitance and uncertainty in Table 1.

Note: *Steps 7 and 8 must be done separately, as in the familiarisation activity.*

9. Connect and configure the signal generator as follows:

- Select a sine wave ∼.
- Set the peak-to-peak input voltage to $V_{\iota\ entrada} = 1\ Vpp$ and do not change it again.

10. Configure the oscilloscope for voltage and frequency measurements. On an oscilloscope,

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voltage is on the Y axis and time on the X axis. Configure it as follows:

- Select channel 2.
- Enable amplitude mode (ampl) until a channel-2 amplitude marker appears.

- Repeat to select frequency (freq). The oscilloscope now displays output-voltage and frequency measurements.

11. Return to the signal generator and select Freq mode at 60 Hz.
12. Return to the oscilloscope and click “Take measurement”. Sine waves appear.
13. Record the frequency and output voltage for channel 2 in Table 1.
14. For every measurement, remember its uncertainty, treating all instruments as digital.
15. Repeat for other frequencies between [100 and 3000] Hz. Record the results in Table 1.
16. Use the collected data to calculate gain. A.

Table 1. Output voltages and frequencies for the low-pass circuit.

$\boldsymbol{V_{entrada} = \ \pm \ \ V \ / \ R = \ \pm \ \ \Omega \ / \ C = \ \pm \ \ F}$

Frequency f (Hz) $\pm$__ $\boldsymbol{Hz}$	Output voltage V_{sal} (V) $\pm$_____ $\mathbf{V}$	Gain A

• *Analysis and fitting* ***(7 points)***

17. Linearise equation 1.
18. Use the data in Table 1 and this expression to plot a graph giving RC and its uncertainty in Table 2.

19. Compare this with the theoretical RC product and enter the results in Table 2.
20. Find the cutoff frequency.

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Table 2. RC-product results

RC product (theory) (τ) ± s	Experimental RC product (τ) ± s	Diff. %

21. Discuss the results in Table 2.

Part B: High-pass circuit

- *Experimental setup*

1. Reopen VISIR HIVE Laboratory or start a new experiment to obtain the workspace in Figure 5.

2. Again use the $\mathbf{1\mu F}$ capacitor and $\mathbf{1k\Omega}$ resistor.

3. On the breadboard, build the circuit in Figure 4 using the resistor and capacitor.

4. Connect the signal generator:

- Connect “Function generator” to the capacitor's first terminal (left on screen).

- Connect its other terminal (right) in series with the resistor's first terminal (left).

- Connect the resistor's other terminal (right) to “GND”.

5. Connect oscilloscope channels to measure the generator and capacitor voltages:

- Connect “Ch1” to the capacitor's first terminal (left, connected to the function generator).

- Connect “Ch2” to the resistor's first terminal (left, in series with the capacitor).

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• *Measurement* ***(3 points)***

6. Using the same resistor and capacitor, enter their actual values from steps 7 and 8 of Part A in Table 3, with their uncertainties.

Note: *Step 6 requires separate measurements, as in the familiarisation activity.*

7. Connect and configure the signal generator, as in Part A, step 9.
8. Configure the oscilloscope for voltage and frequency measurements (Part A, step 10).
9. Return to the signal generator and set a frequency of 30 Hz.
10. Return to the oscilloscope and click “Take measurement”.
11. Record the frequency and output voltage for channel 2 in Table 3.
12. For every measurement, consider its uncertainty, treating all instruments as digital.
13. Repeat for other frequencies between [30 and 3000] Hz. Record the results in Table 3.
14. Use the data to calculate gain.
A.

Table 3. Output voltages and frequencies for the high-pass circuit.

$\boldsymbol{V_{entrada} = \ \pm \ V \ / \ R = \ \pm \ \Omega \ / \ C = \ \pm \ F}$

Frequency f (Hz) $\pm$__$\boldsymbol{Hz}$	Output voltage V_{sal} (V) $\pm$_____$\mathbf{V}$	Gain A

• *Analysis and fitting* ***(7 points)***

15. Linearise equation 2.
16. Use Table 3 and the expression from the preceding step to plot a graph giving RC and its uncertainty in Table 4.

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17. Compare it with the theoretical RC product and enter the results in Table 4.

18. Find the cutoff frequency.

Table 4. Cutoff-frequency results

RC product theory (τ) ± s	RC product (exp.) (τ) ± s	Diff. %

19. Discuss the results in Table 4.

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Experimental Problem: Answer guide

Suggestions and instructions for submitting answer sheets

A. Do not put your name on the answer sheets.

B. Present all answers neatly.

C. Follow the problem's order and numbering for your answers.

D. Write answers on blank sheets without logos or other markings.

E. Graph paper must also be free of markings.

F. Scan every sheet used for answers.

G. Do not add any sheets used as rough-work paper to your answer document.

H. Do NOT upload **any** pages of this experimental problem to the platform; any such page is invalidated.

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